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DETERMINATION OF SMALL CRAFT LEEWAY

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16. Abstract

Small craft (<22 feet) leeway is determined as a function of the wind speed in the range of 5-20 knots to enable more precise forecasting of the leeway drift of a distressed surface vessel at sea. Leeway is calculated by measurement of the separation distance of the small craft from a dyed patch of surface water at sea, using time-sequenced aerial photography. Leeway increases linearly with wind speed for small craft equipped with or without a sea anchor in the wind range studied. Leeway for small craft without sea anchor can be calculated from the equation $U_L = 0.07\ U_W + 0.04$ where U_W is the wind speed at 2 meter elevation. Leeway for small craft with sea anchor can be calculated from the equation $U_{LD} = 0.05\ U_W - 0.12$. The small craft drifted off the downwind direction in about 80% of the experiments. The drift angle is variable and difficult to predict.

U sub L

U sub W

U sub LD

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PREFACE

One of the primary missions of the U.S. Coast Guard is the search and rescue of persons and property in distress on and over the high seas and navigable waters. To accomplish this mission, the Coast Guard must have the capability to accurately predict the position of the survivors who are at the mercy of the winds and surface currents.

The Coast Guard Research and Development Center is presently conducting research on a model for prediction of total drift of an object on the water. The model takes into consideration both the effects of the wind (leeway) and the surface current. This report deals with the effect of wind on small surface vessels. It is hoped that the results of this study will contribute to our growing knowledge on how to conduct the most successful search for an object on the water.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

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SUMMARY

The primary objective of this project is to measure small craft leeway by using time-sequenced aerial photographic recording of separation distances of small (<22 ft.) craft drifting from a dye patch on the water. The dye patch is assumed free of windage (zero leeway) and moves essentially with the sea surface current. Any subsequent drift of the small craft away from the dye patch is caused by the action of the wind on the craft (leeway).

Five small craft (Mariner, Glastron, Barge, Silver Skif, and a rubber raft were used in leeway experiments conducted in the coastal waters off Southeastern Connecticut. The following are summaries of the major results from 102 exercises.

1. The five small craft exhibited similar leeway as a function of wind speed. Although sail area, keel area and weight varied considerably among the craft, these variables had no observable effect on leeway speed.

2. Leeway for small craft without a drogue (sea anchor) in the wind range of 5-20 knots may be computed from the expression

$$U_L = 0.07\ U_W + 0.04,$$

where U_L and U_W are the leeway and wind speed in knots.

3. The relationship between leeway and wind speed is complex at wind speeds below 5 knots. An expression cannot be predicted for low winds.

4. Leeway of small craft with a drogue in the wind range of 5-20 knots may be computed from the expression

$$U_{LD} = 0.05\ U_W - 0.12,$$

where U_{LD} and U_W are the leeway and wind speed in knots, respectively.

5. Small craft drift off the downward direction about 80% of the time. Once the small craft begins to drift to one side of the wind direction the craft tends to remain to that side of the wind during the drift, or until the wind shifts direction.

6. The drift angle for a specific small craft can vary by as much as a factor of seven at the same wind speed. This variation of direction occurs because of the many different headings the boat assumes to the wind, and the effect of the keel.

7. Small craft leeway appears to increase up to about 15% with increasing sea state but the relationship has not been quantitatively established.

BACKGROUND

When a surface vessel is adrift in the ocean its transactional behavior can be described in terms of two major factors: the speed and direction of the surface current and the speed and direction of the local wind. Some effort has been made to determine the effects of the surface current on a drifting object (Tomczak, 1964; James, 1966; Meyer et al, 1969). So far, only a few scattered contributions exist in the literature to throw light on the magnitude and direction of the wind on a drifting object. Leeway is defined as the movement of an object through the water caused by wind acting on the object.

The U.S. Navy Hydrographic Office (1944) produced a chart depicting the leeway magnitude of a rubber raft with and without a drogue (Fig. 1). For a loaded raft without a drogue, leeway speed varied from one-half knot with a four-knot breeze to about one knot with a twenty-knot wind. Leeway direction was considered to be directly downwind. When a drogue was used, the leeway speed of the rubber raft was reduced to less than three per cent of the wind speed.

The leeway speed of the rubber raft with drogue can be expressed as a function of the form

$$y = ax + b, \qquad (1)$$

where y is the leeway speed, x is the wind speed, and a and b are respectively the slope of the line and the y intercept. The leeway speed of the rubber raft without a drogue as a function of wind speed can be expressed as a power curve of the form

$$y = mx^n, \qquad (2)$$

where y is the leeway speed, x is the wind speed and m and n are terms of the power curve. The equation can be linearized by taking logarithms and solving for the values of m and n by the method of least squares.

These two curves for the leeway speed of the rubber raft (with and without drogue) are presently used in the National Search and Rescue Manual (CG-308) for predicting the leeway of drifting surface vessels. The two curves are intended to represent the extreme magnitude of leeway. The leeway for all other types of surface craft are thought to fall between the two curves.

Chapline (1959) conducted a series of leeway experiments on the waters near Honolulu, Hawaii using a number of small surface craft without drogue. His primary objective was to determine the leeway rate for various types of drifting small craft and compare his findings with the leeway rate given in the National Search and Rescue Manual. Chapline's results are presented in Table 1.

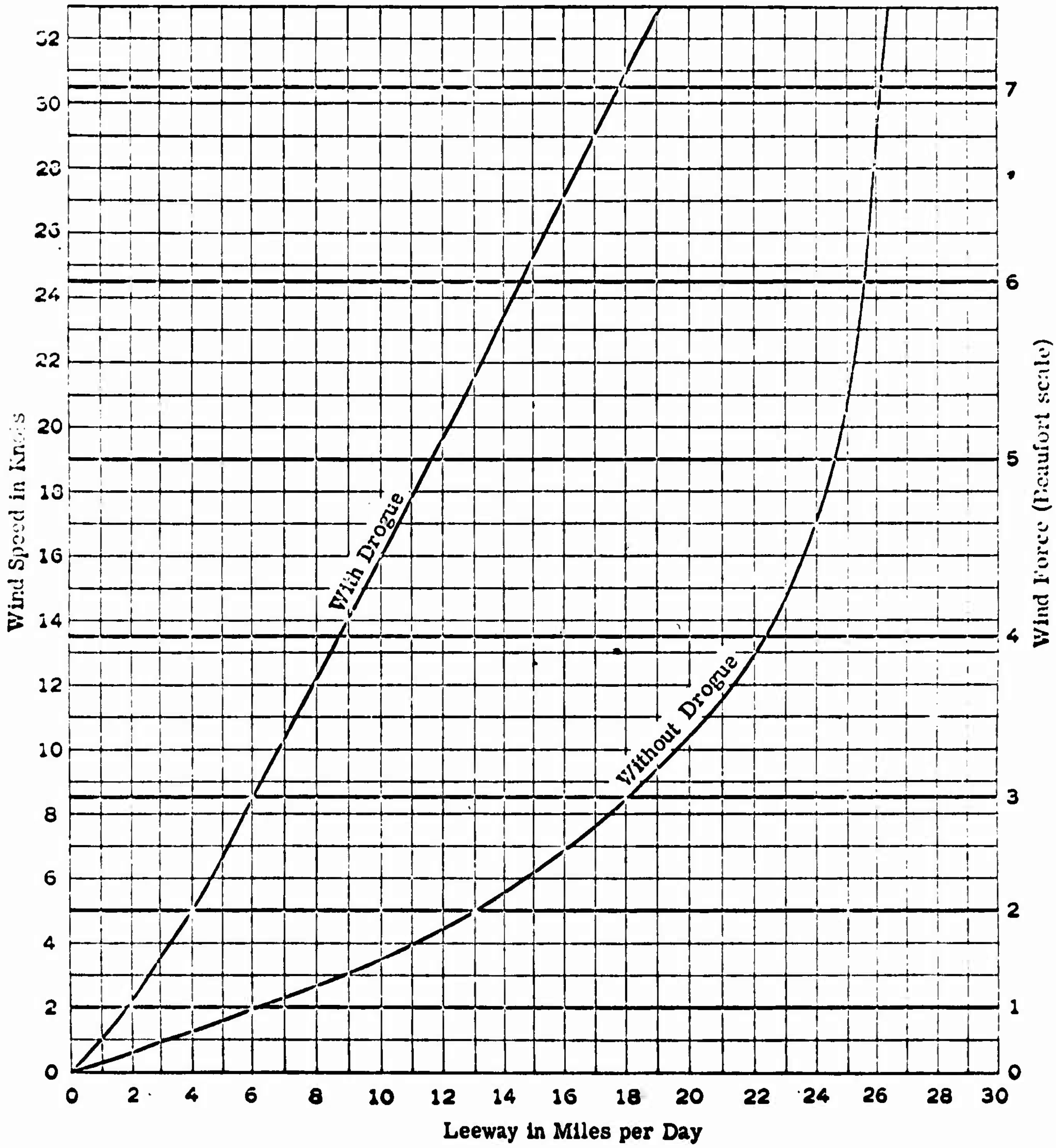

Figure 1. Leeway of a rubber raft with respect to the wind speed or force (from U.S. Navy Hydrographic Office, 1944).

Table 1. Leeway rates of several drift objects expressed as a percent of the wind velocity W (from Chapline 1959).

DRIFT OBJECT	LEEWAY (Percent of wind speed, W)
Surfboard	2% W
Heavy displacement, deep draft sailing vessels	3% W
Moderate displacement, moderate draft sailing vessels and fishing vessels such as trawlers, trollers, sampans, draggers, seiners, tuna boats, halibut boats, etc.	4% W
Moderate displacement cruisers	5%
Light displacement cruisers, outboards, planing hull types, skifs, etc.	6% W

Most important, Chapline found that the leeway speed of the small craft without a drogue is directly proportional to the wind velocity (at least for moderate to fresh winds). The author gave no indication that any of the small craft leeway could be expressed as a power function.

Chapline also noted that many of the surface craft in the experiments did not drift directly downwind. The tendency to move off the wind line was most pronounced in vessels with a large draft to given displacement rates; i.e., having a large lateral plane. The angle of deviation varied from 20° to 40° off the wind. No mention was made of whether the deviation was always to the right, or to the left of the wind, or both.

Chapline's results vary significantly from the results given by the U.S. Navy Hydrographic Office. The Navy report states that the leeway magnitude of small craft without drogue is exponentially related to the wind speed while Chapline states that the leeway is directly proportional to the wind speed. The Navy study also assumes that leeway drift is approximately downwind. Chapline's results indicate that a small craft with deep draft has a tendency to move off the wind line by as much as 40°.

The computer - assisted search planning system (CASP) currently employed by the Coast Guard for application in search and rescue uses the following equation to compute leeway as a function of wind:

$$L = aW^{b}e$$

where W is the wind speed in knots, L is the leeway in knots, a and b are the terms of the power curve, and e is the error term (expressed as 1 ± c where c is a percent error). This equation is based on the early work at Woods Hole Oceanographic Institution which was published by the U.S. Navy Hydrographic Office (1944).

The primary objective of this project was to measure small craft leeway by using time-sequenced aerial photographic recordings of separation distances of small surface craft from a dye patch on the water.

EXPERIMENTAL PROCEDURES

METHOD

The leeway experiments were conducted in the waters of Fisher's Island Sound and Block Island Sound off Southeastern Connecticut. The experimental method consisted of assembling four or five target small craft in close proximity, releasing a liquid fluorescein dye on the water surface, and allowing the vessels to drift. The dye patch is assumed to be free of windage (zero leeway) and moves essentially with the sea surface current, as do the boats.

As the small craft began to drift away from the dye patch, the boat pattern was photographed every five minutes from the air, usually from an altitude of 5000 ft. Wind speed, direction and sea state were monitored during each experiment by personnel aboard one of the drifting vessels. The wind speed and direction were recorded at five-minute intervals from a portable cup-anemometer held at a two-meter elevation above the water. Relative wind direction was corrected to actual wind direction by using the small craft's magnetic compass.

Duration of any experiment ranged from 40 to 180 minutes. The length of time depended on how long it took for the separation distance between the small craft and the dye patch to become too great for inclusion in a single photograph. Experiments also were termiated when the drift objects approached land or a shear zone in the water.

TARGET VESSELS

Twenty-two different small craft ranging from 9 to 42 feet in length were used in the project. For this report five of those vessels were examined in detail. There are insufficient data on the remaining craft for this analysis. Pertinent information on the five small craft are summarized in Table 2. During the experiments, actual people or sandbags representing passengers were placed in the small craft to simulate real conditions. The "sail area" is the total braodside area of the vessel which extended above the waterline, and the "keel plane area" is that broadside area extending below the waterline.

Table 2. Characteristics of five small craft used on the leeway experiments.

BOAT TYPE	LENGTH (FT.)	WEIGHT (lbs.)	SAIL AREA (Sq. Ft.)	KEEL PLANE AREA (Sq.Ft.)	KEEL/SAIL RATIO
MARINER	21	1191	48.0	8.1	.169
GLASTRON	15.2	1069	24.3	17.1	.704
BARGE	15	255	18.2	1.1	.060
SILVER SKIF	12	115	16.4	3.3	.201
RUBBER RAFT	12	50	13.9	0.1	.007

AERIAL PHOTOGRAPHY

The aerial photographs of the experiments were obtained with two nadir-viewing, motor driven, 70 mm Hasselblad cameras mounted side-by-side in a single engine aircraft. Each camera was equipped with ordinary daylight color film. This film provided good definition and sufficient resolution of the components of an experiment from the 5000 feet altitude flown by the aircraft. Normally only one exposure per pass of the aircraft was made.

Synchronized with the two 70 mm cameras was a 50 mm single-lens reflex camera used to obtain black-and-white photographs of the aircraft instrument panel. The photograph of the panel provided direct information on altitude, heading and time. The pilot maintained an inflight data log on frame numbers, time of exposure and other pertinent observations.

FILM MEASUREMENTS

The film strips obtained from each experiment were developed by a commercial processer, then numbered by frame and experiment. Each frame was then analyzed to determine the position of each drift object with respect to the centroid of the dye patch. The centroid of the dye patch and the center of each drift object were visually estimated. The distance and angles between each object and the dye patch were measured using a stage micrometer scale.

To insure accuracy, two methods were employed to determine a scaling factor to convert measured film distances to actual distances. The first method involved computing the scaling factor by dividing the aircraft altitude (H) by the camera focal length (CFL) and obtaining the photo scale reciprocal (PSR). The photo scale reciprocal was then multiplied by the measured film distance between the dye patch and drift object to obtain actual ground distance. The second method used to produce a scaling factor involved comparing a known length of a large object (in this case a local airport runway) with the size of the drift objects from the same altitude. This ratio was applied to the separation distances measured on the film to convert to actual scale.

RESULTS

A total of 102 experiments have been conducted in the coastal waters off Southeastern Connecticut since November 6, 1972. The measurements were made using small craft with and without a drogue. The results from each experiment have been plotted on progressive vector diagrams to show the frame-by-frame leeway movement of each small craft. Examples of such vector diagrams are presented in Figures 2-5. Note in the figures that wind speed is given as a range; 0-5, 5-10, 10-15, and 15-20 knots. In actual search and rescue cases, the search planner does not know the specific wind speed at the scene of distress and he must work with a wind speed range. Although average wind speed was used in the computations of leeway in this report, attempts were made to accurately predict leeway from a wind speed range of 5 knots span.

LEEWAY SPEED - WITHOUT DROGUE

The values of the experimentally determined mean leeway, U_L, for five small craft without drogue and associated wind speed values, U_W, are summarized in Table 1 in the Appendix. Each mean value given in the table is a result of multiple determinations from each experiment.

The mean leeway speed for each small craft is plotted against the associated wind speed values in Figures 6-10. The function best fitting to the data was found to be a linear equation determined by the method of least squares (Mendenhall, 1965):

$$U_L = a_0 + a_1 U_W, \qquad (3)$$

where U_L is the leeway speed, U_W is the wind speed and a_0 and a_1 are the regression coefficients (a_0 is the y intercept, a_1 is the slope of the line). The coefficients a_0 and a_1 for each small craft along with the measure of linear correlation, r^2, are given in Table 3. (For an explanation of the statistics see Table 3 in Appendix.)

Table 3. Values of the regression coefficients for linear estimation of small craft (without drogue) leeway as a function of wind speed.

BOAT TYPE	a_0	a_1	r^2	NO. OF EXERCISES
MARINER	0.01	0.06	0.75	50
GLASTRON	-0.02	0.06	0.77	38
BARGE	-0.08	0.08	0.80	33
SILVER SKIF	0.11	0.07	0.63	40
RUBBER RAFT	0.17	0.06	0.71	21

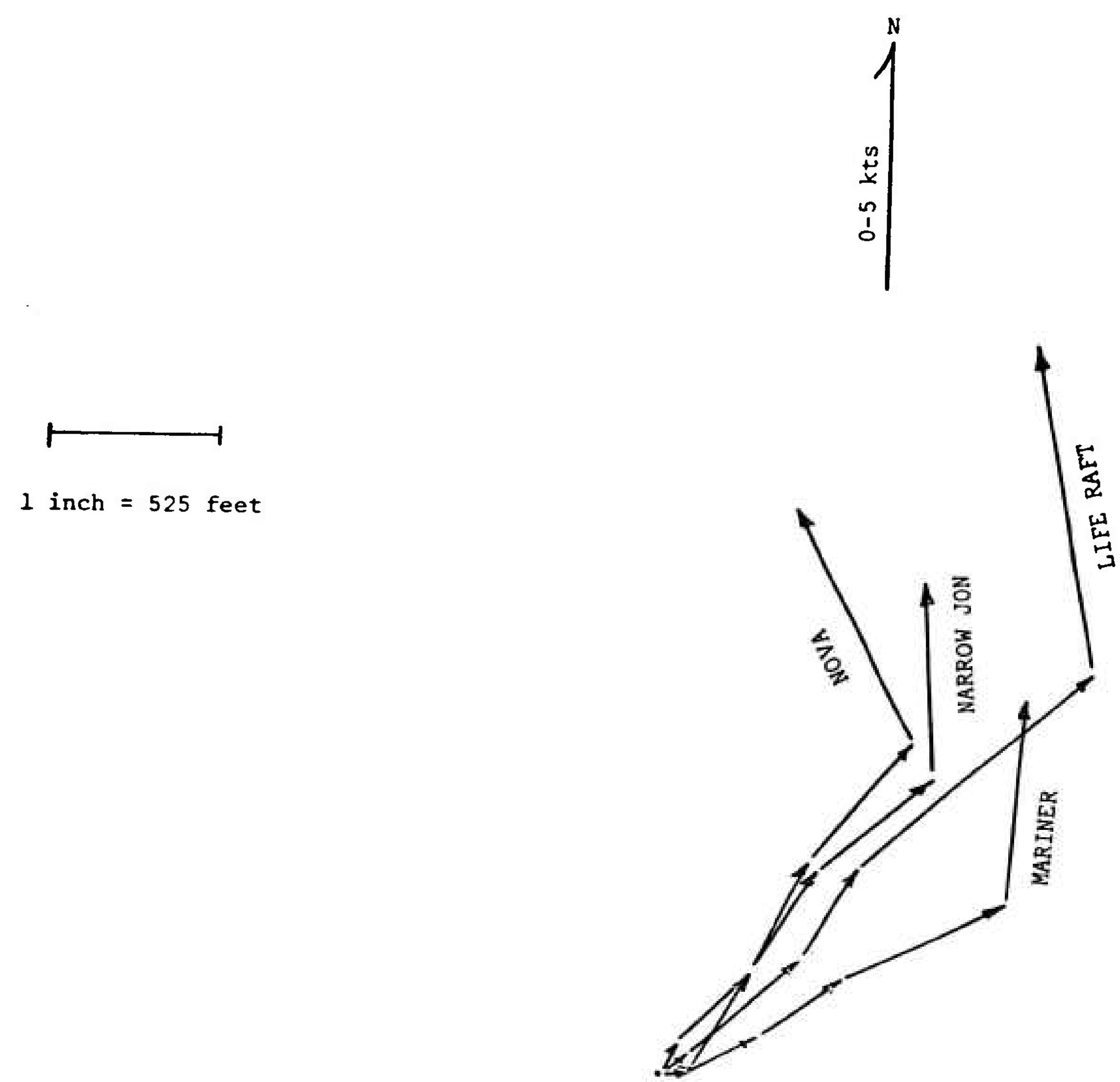

Figure 2. Vector diagram of the leeway of four small craft at 0-5 knots wind speed.

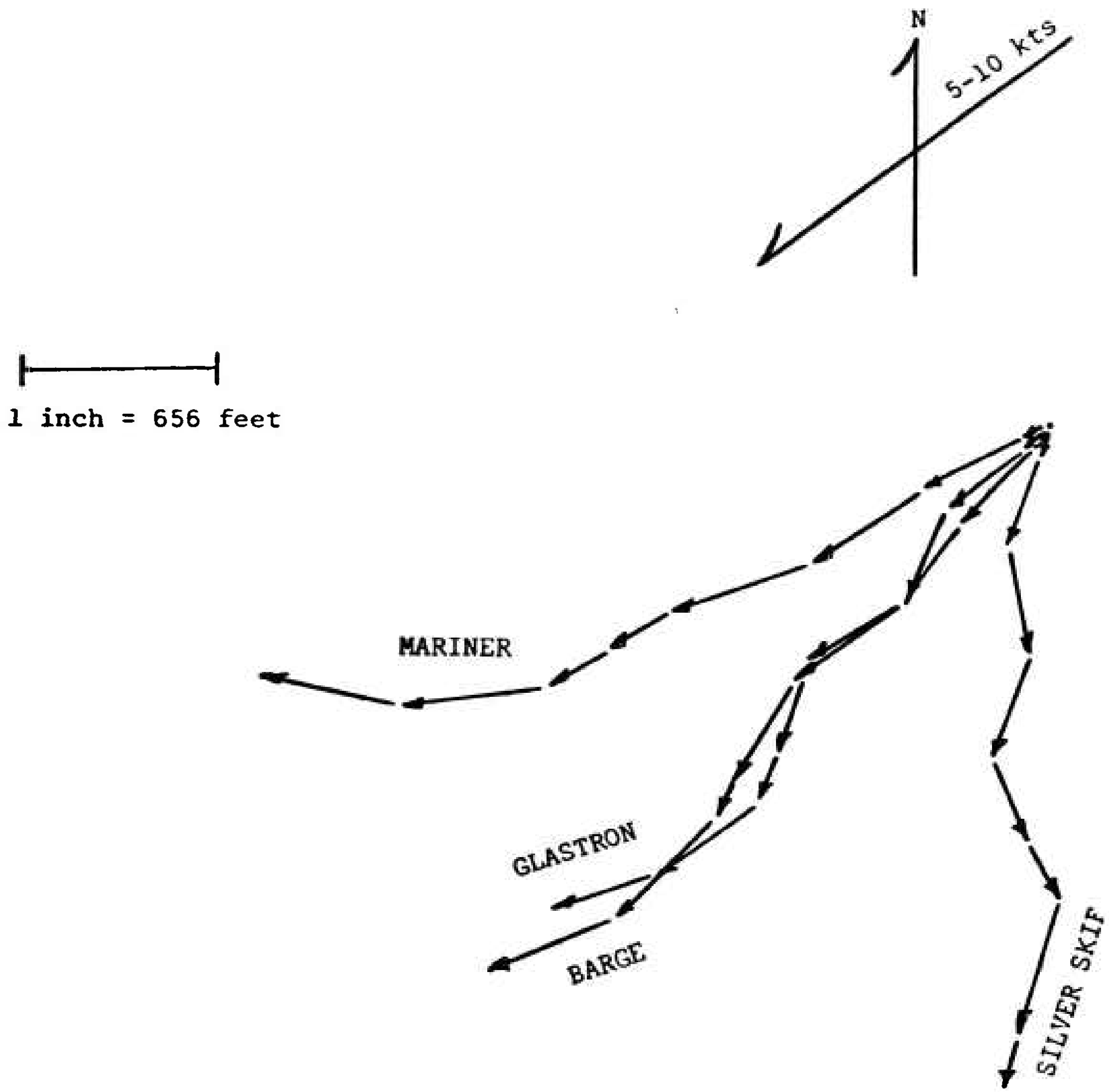

Figure 3. Vector diagram of the leeway of four small craft at 5-10 knots wind speed.

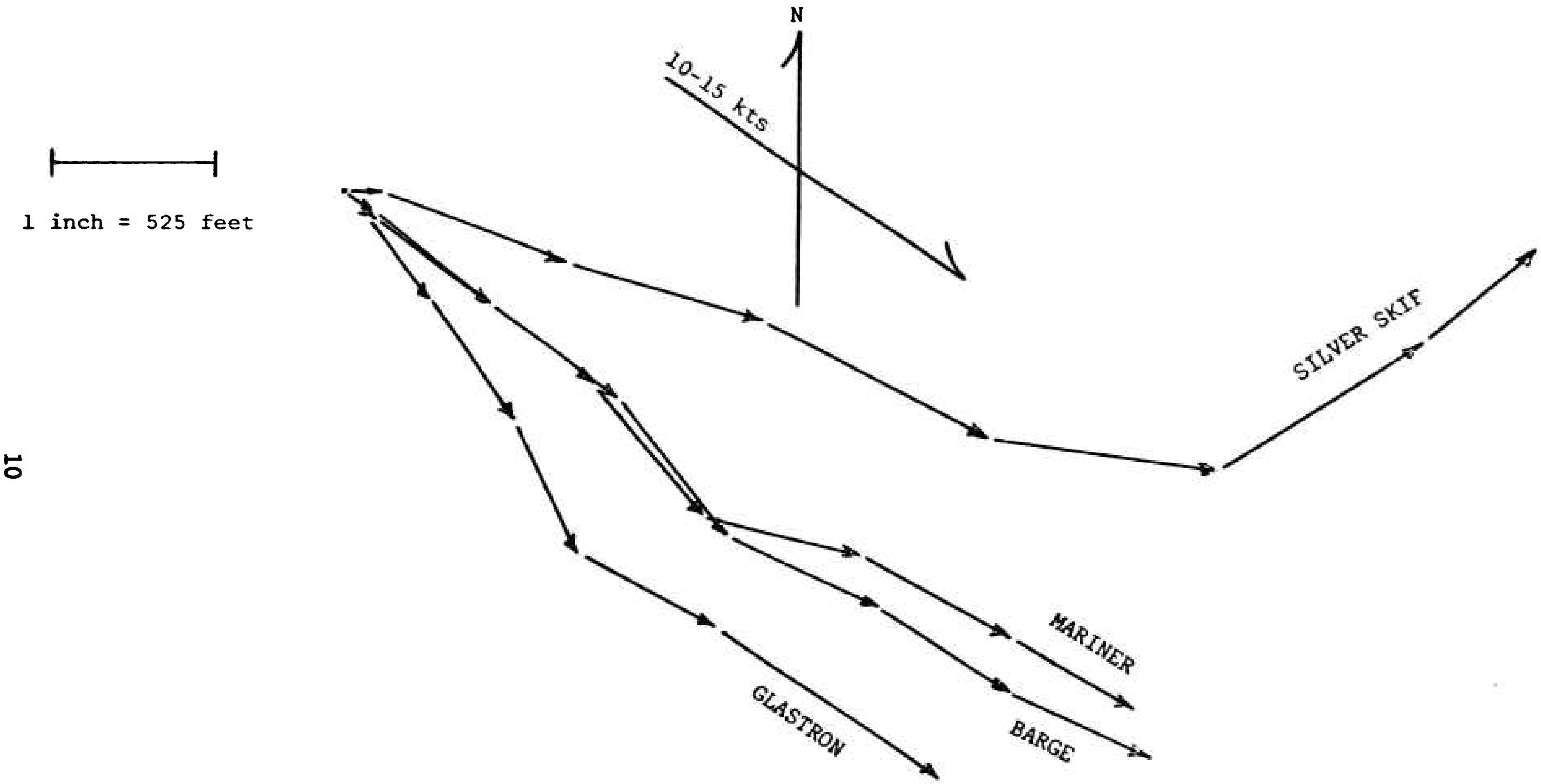

Figure 4. Vector diagram of the leeway of four small craft at 10-15 knots wind speed.

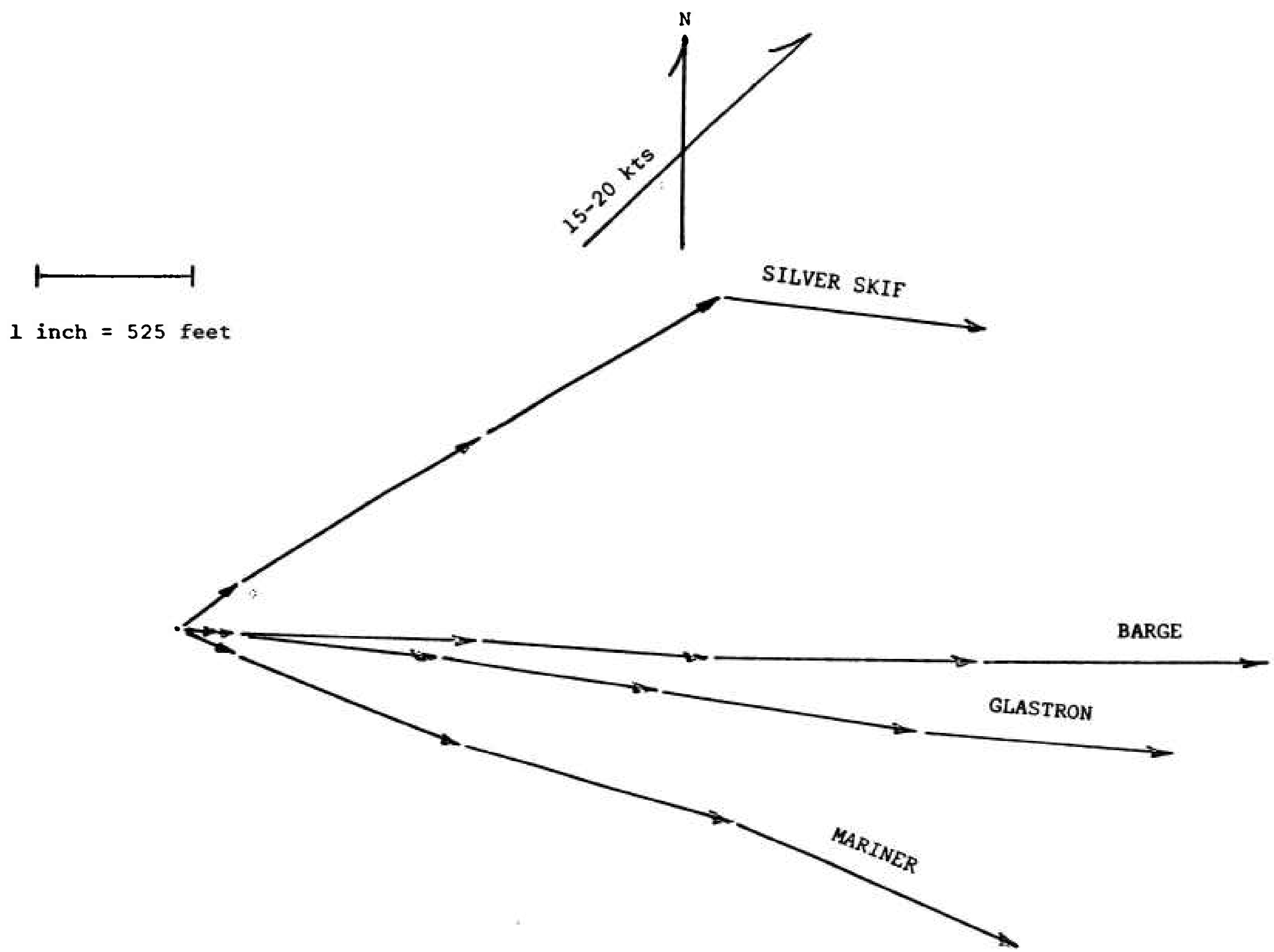

Figure 5. Vector diagram of the leeway of four small craft at 15-20 knots wind speed.

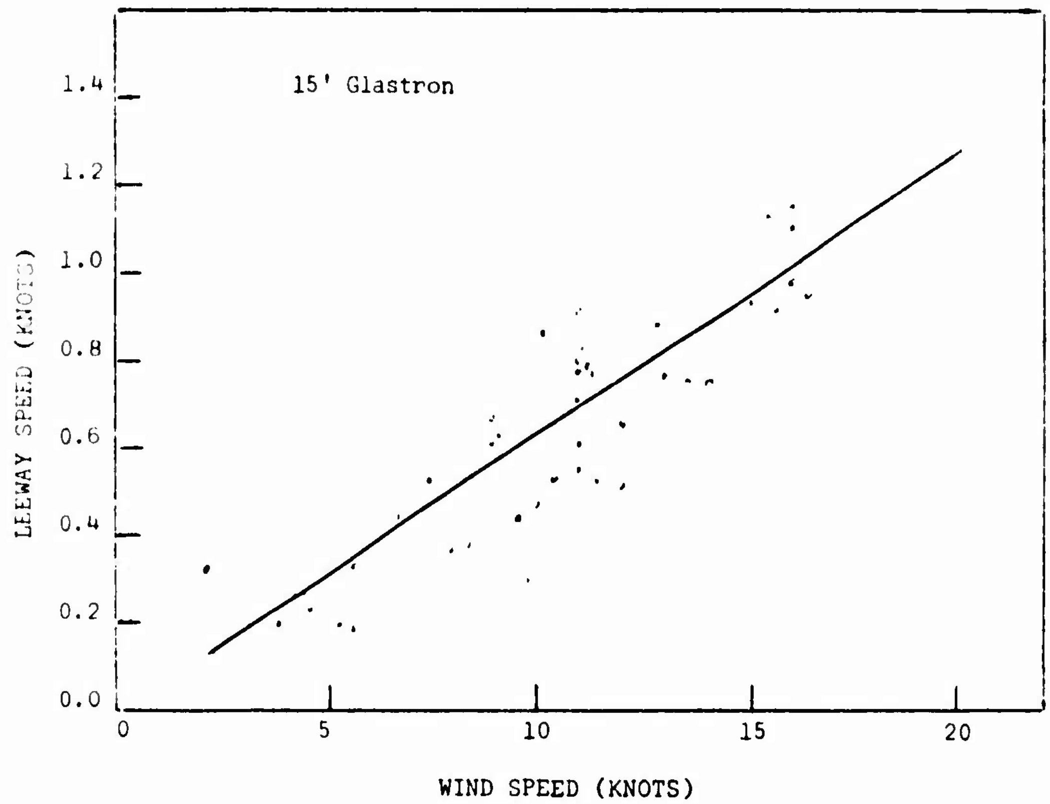

Figure 6. Leeway of the 15' Glastron as a function of wind speed.

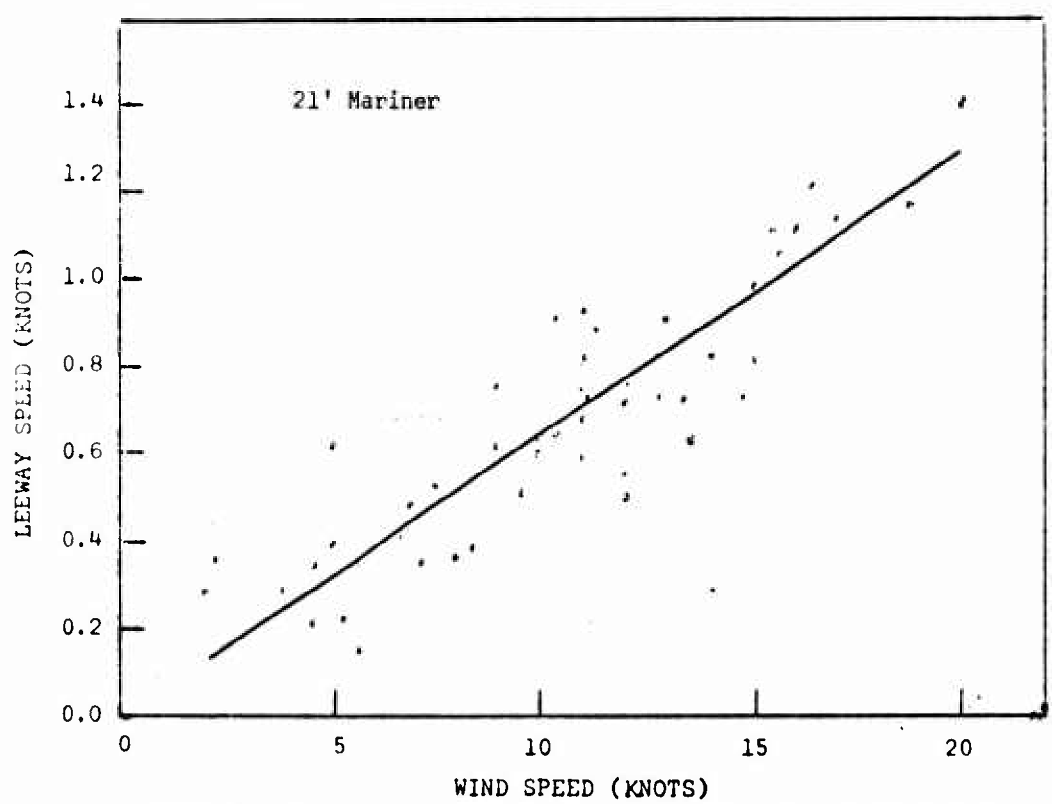

Figure 7: Leeway of the 21' Mariner as a function of wind speed.

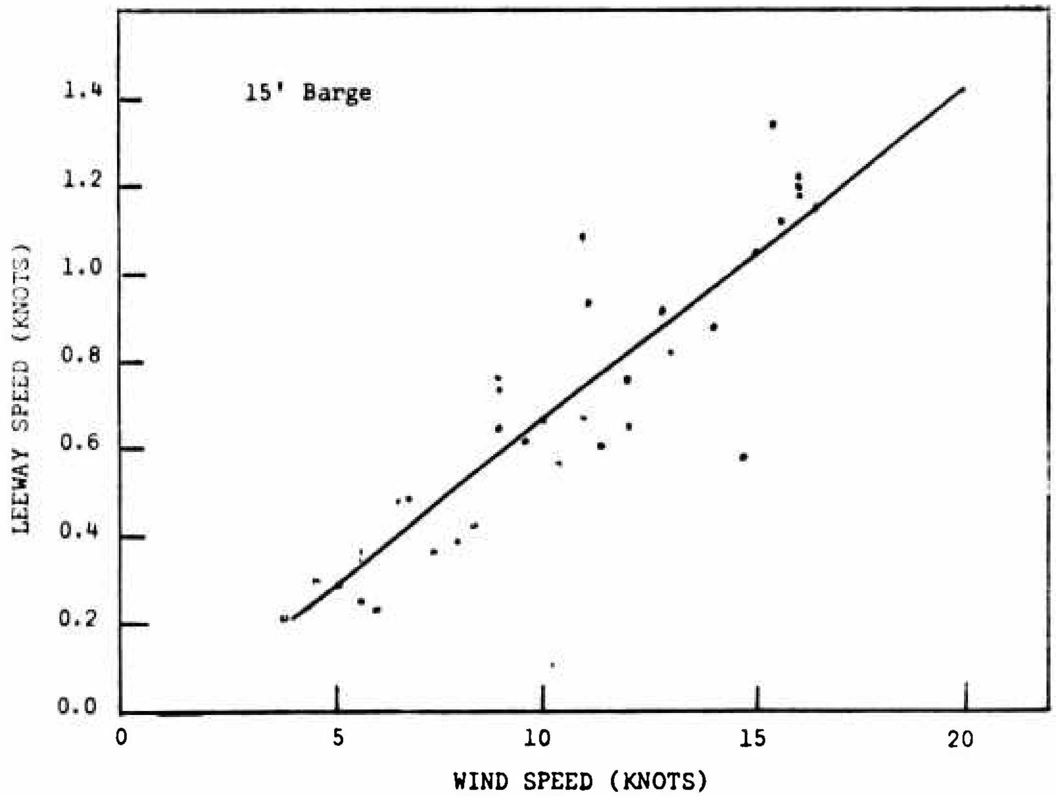

Figure 8. Leeway of the 15' Barge as a function of wind speed.

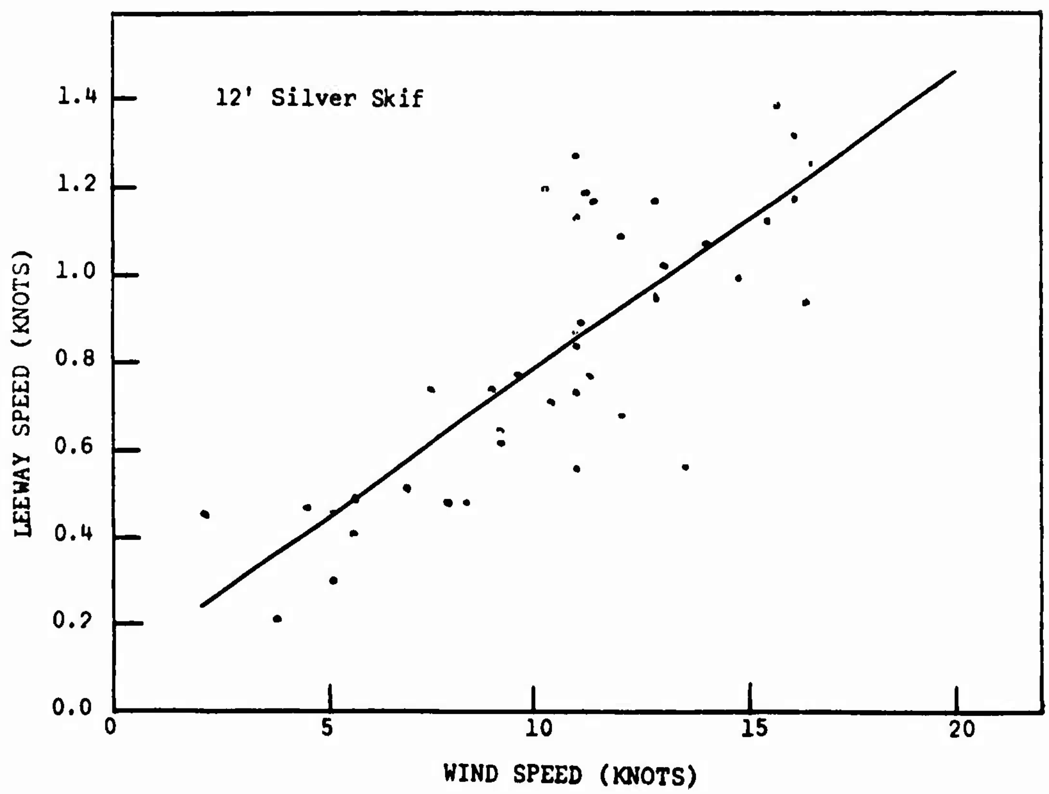

Figure 9. Leeway of the 12' Silver Skif as a function of wind speed.

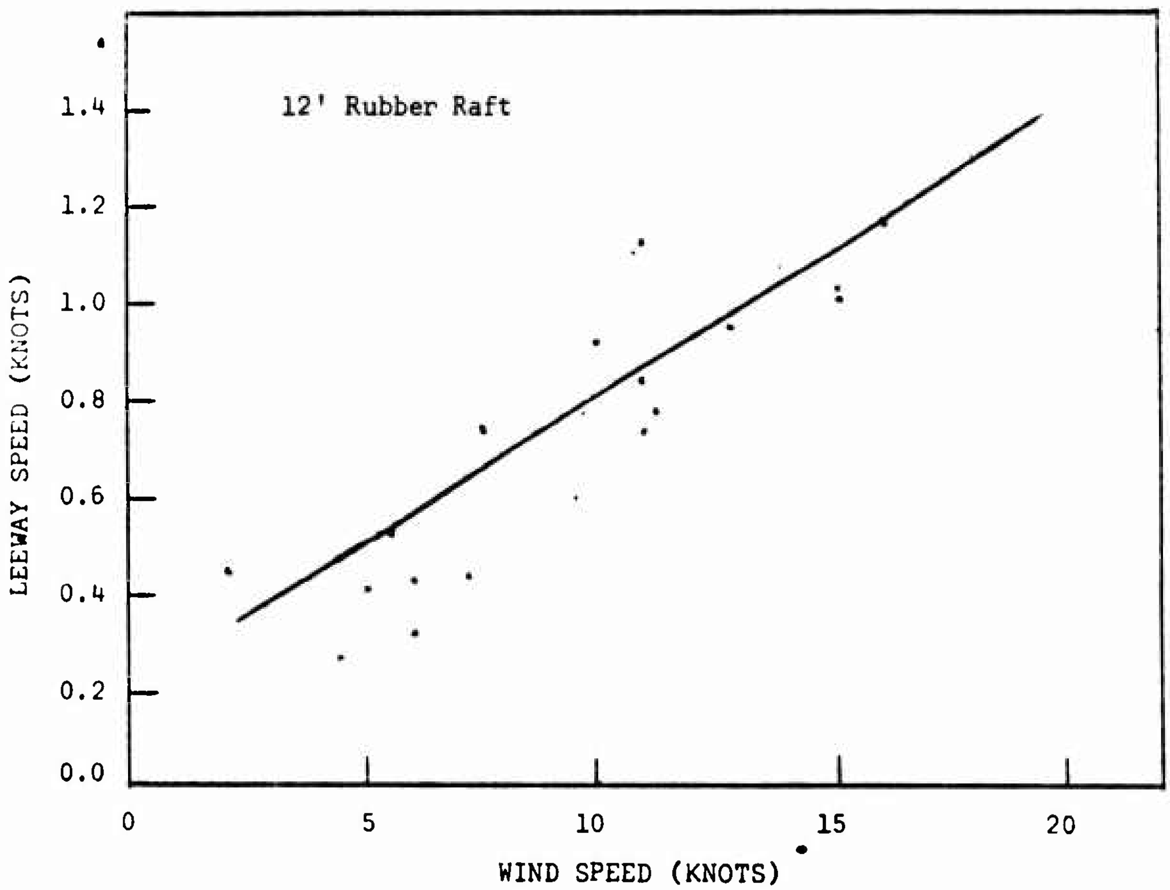

Figure 10. Leeway of the 12' Rubber Raft as a function of wind speed.

The most interesting feature revealed in Table 3 is that the slope of the line (a_1) for all the five small craft is nearly identical even though the individual keel to sail area ratios of the different small craft vary by as much as 100%. Also the weights of the craft vary from 50 to 1190 pounds (Table 2). Unexpectedly, there appears to be no systematic relationship between the coefficient a_1 with weight, sail area or keel area; these factors will be discussed later (see Leeway Direction).

A statistical F test (Mendenhall, 1965) demonstrated that the differences between the five generated regression functions were not significant and thus a single equation for all five small craft can be produced to predict leeway. The single equation for leeway speed of all small craft without drogue between a wind speed of 5 and 20 knots is:

$$U_L = 0.04 + 0.07\, U_W, \tag{4}$$

The values of leeway predicted by the single equation are given in Table 4.

Table 4. The predicted leeway values of small craft without drogue.

WIND SPEED U_W (knots)	LEEWAY SPEED U_L (knots)	90% CONFIDENCE LIMITS	LEEWAY IN N. MILES PER DAY	LEEWAY AS % OF WIND
5	0.39	±0.07	9.36	7.8
10	0.74	±0.06	17.76	7.4
15	1.09	±0.06	26.16	7.3
20	1.44	±0.07	34.56	7.2

The drift of small craft produced by the action of the wind is frequently described in terms of a wind factor: the drift rate as a percentage of wind speed. The wind factor from the data in these experiments is 7.4%. This value is somewhat larger than the 6% observed by Chapline (1959), but is still close to his findings. For comparison purposes, the wind factor for oil slicks is about 2% (Smith 1974).

The coefficient a_0 in the single equation (4) indicates that at zero wind speed a small craft will have a leeway speed of 0.04 knots. This would appear to contradict the definition of leeway. But leeway data collected at wind speeds of less than 5 knots suggest that the leeway to wind relationship may not be linear between zero and 5 knots. The data show considerable scatter; and the non-linear relationship below 5 knots is not so surprising if one considers that a "threshold" wind velocity must be reached before a small craft begins to display leeway. The "threshold" value probably depends on both the attitude of the small craft to the wind and the craft's inertia. It appears that the "threshold" value occurs between sero and 5 knots; but because of its considerable variability the "threshold" value cannot be specifically defined. The single leeway equation given for small craft without drogue is valid only for wind speeds of 5 to 20 knots.

For search and rescue purposes the function describing the leeway to wind relationship below 5 knots need not be exactly defined because the total leeway drift of a small craft at these low winds would be less than 9 nautical miles per day.

LEEWAY SPEED - WITH DROGUE

Many of the inflatable, automatically-deployed life rafts are now equipped with water pockets or ballast buckets to stabilize the raft. Also many other types of small craft are equipped with a drogue or sea anchor. These devices increase drag and reduce leeway. The experimental leeway data collected on four small craft with a drogue and associated wind speed values are summarized in Table 2 of the appendix. The data are plotted against the associated wind speed values in figures 11-14.

The function best fitting the data was found to be a linear equation determined by the least squares method. The regression coefficient, a_0 and a_1, and their correclation coefficient, r^2, are given in Table 5.

Table 5. Values of the regression coefficients for linear estimation of small craft with drogue as a function of wind speed.

BOAT TYPE	a_0	a1	r2	NO OF EXERCISES
MARINER	-0.12	0.06	0.89	16
GLASTRON	-0.09	0.05	0.72	11
SILVER SKIF	-0.07	0.04	0.70	11
RUBBER RAFT	-0.20	0.04	0.83	10

A single equation to predict leeway of small craft equipped with a drogue can be produced following the same assumptions and statistical tests used on leeway of small craft without drogue. The equation is:

$$U_{LD} = -0.12 + 0.05\ U_W, \qquad (5)$$

The values of leeway for all the small craft with drogues in the wind range from 5 to 20 knots predicted by equation (5) are given in Table 6. Data for wind speeds in the range of 0-5 knots were not collected; therefore equation (5) is not valid for wind speeds less than 5 knots.

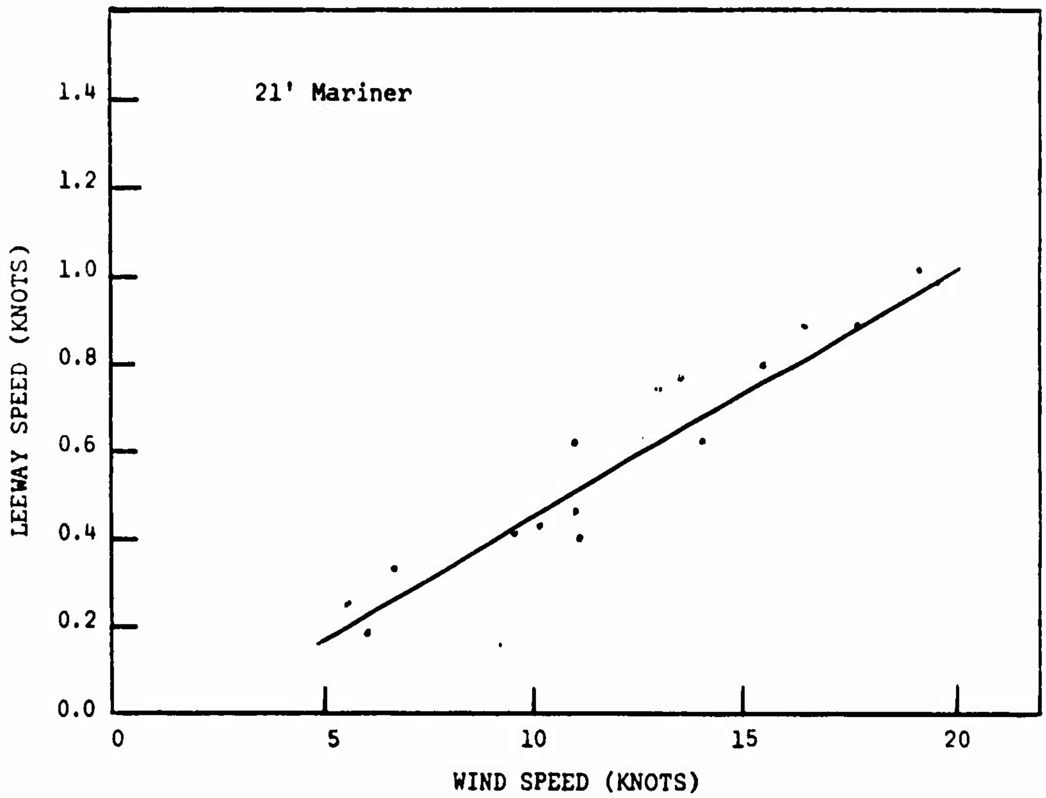

Figure 11. Leeway of the 21' Mariner with drogue as a function of wind speed.

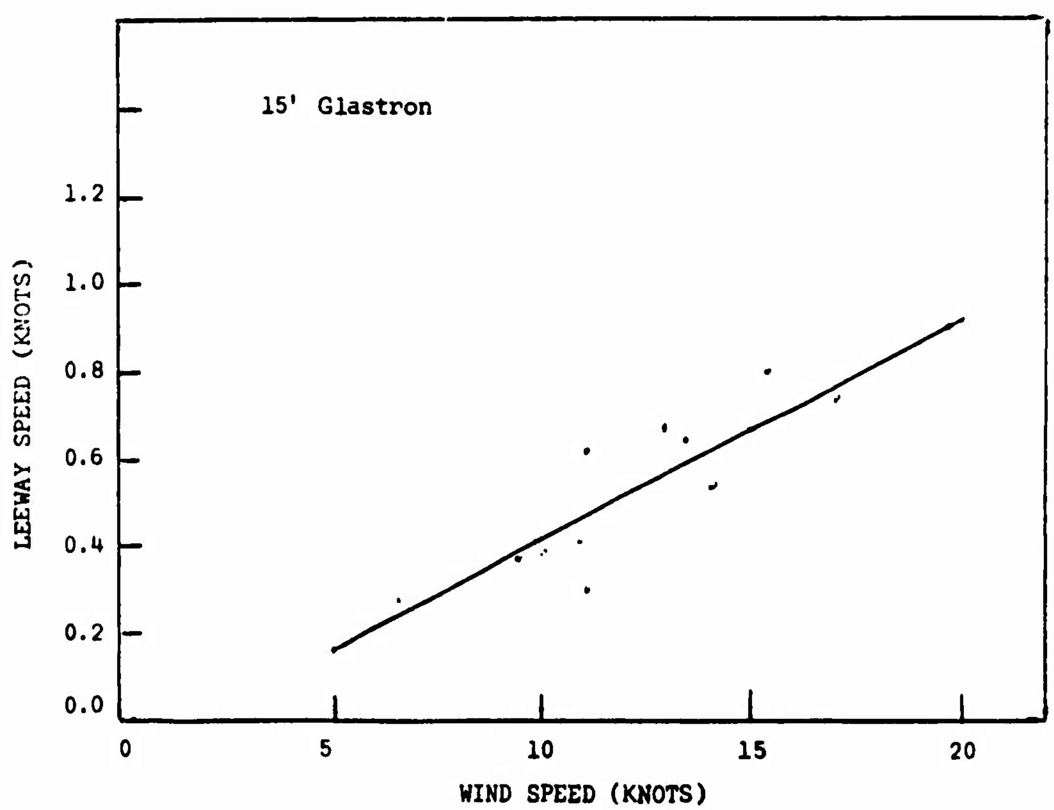

Figure 12. Leeway of the 15' Glastron with drogue as a function of wind speed.

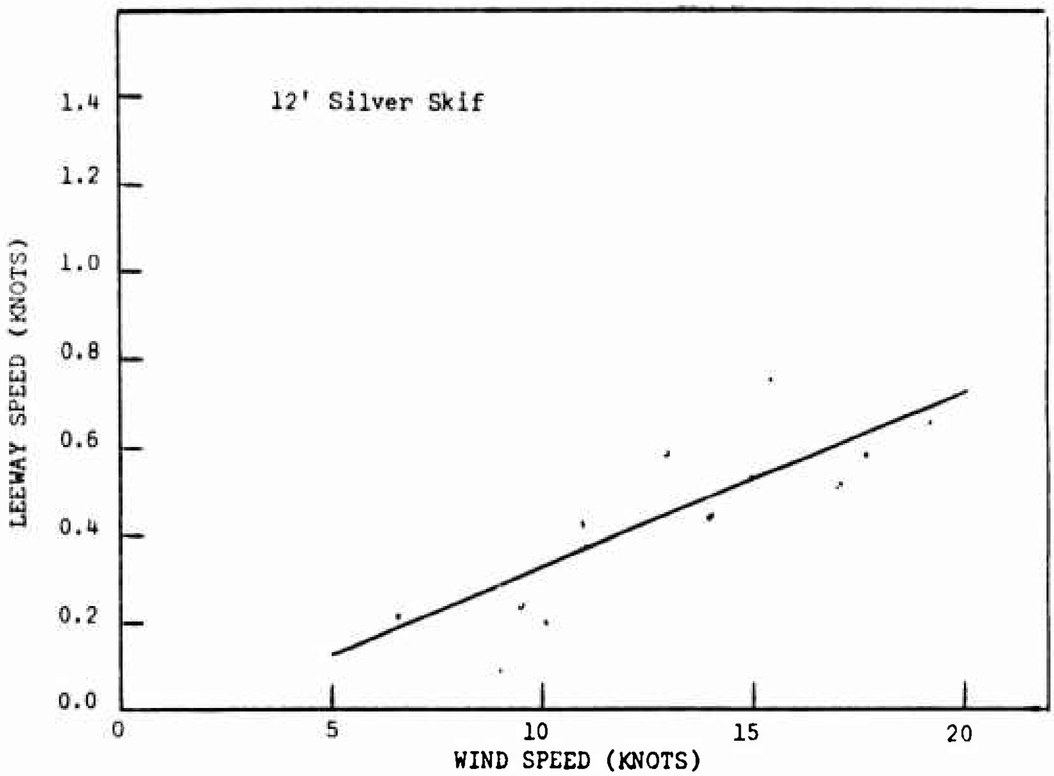

Figure 13. Leeway of the 12' Silver Skif with drogue as a function of wind speed.

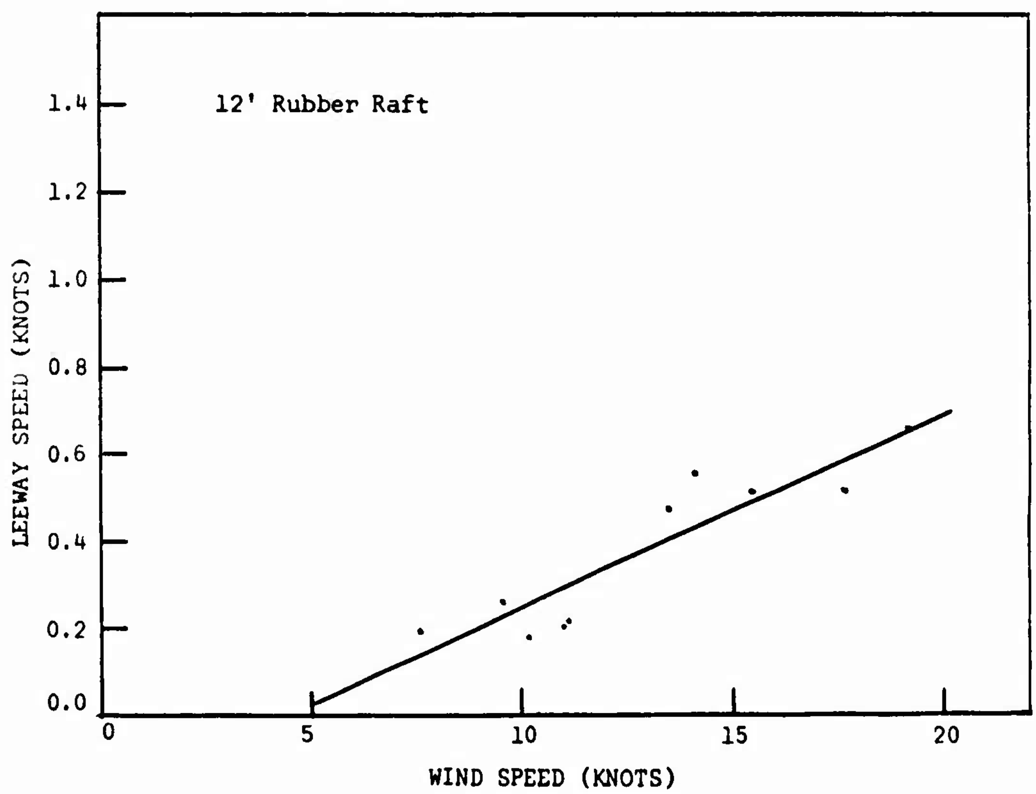

Figure 14. Leeway of the 12' Rubber Raft with drogue as a function of wind speed.

Table 6. Predicted values of small craft leeway (with drogue).

WIND SPEED U_W (knots)	LEEWAY U_L (knots)	90% CONFIDENCE LIMITS	LEEWAY IN N. MILES PER DAY	LEEWAY AS % OF WIND SPEED
5	0.13	±0.05	3.1	2.6
10	0.38	±0.07	9.1	3.8
15	0.63	±0.10	14.4	4.2
20	0.88	±0.13	21.1	4.4

LEEWAY DIRECTION

All the small surface craft used in the leeway experiments exhibited a greater tendency to drift off the true wind direction rather than drift directly downwind (for analysis purposes, direct downwind drift is considered to be drift of less than 5° off the true wind line). Once the craft began to drift to one side of the wind line it tended to remain to that side of the wind during the entire experiment. Examination of the aerial photographs shows that the attitude of the drifting vessels with respect to the wind direction did not change appreciably during an experiment. As an example, if a vessel was drifting predominantly to the right of downwind and happened to drift somewhat to the left, the vessel was most likely to shift back to the right rather than at that point continue drifting to the left, because the vessel attitude did not change. Table 7 shows the percentage of time that five small craft without drogue drifted off the downwind direction.

It is interesting to note in Table 7 that when a small craft did drift off the downwind direction there was an approximately equal chance that it would be either to the left or to the right of the wind. This result indicates that the Coriolis deflection does not affect the direction or set of leeway. In the northern hemisphere the Coriolis deflection is to the right, yet data show that the small surface craft went to the left almost as often as they went to the right. There is a frictional coupling between the small craft and the surface of the water which tends to resist the Corolis deflection. Also, the direction of drift depends on the presence of a keel on many of the craft. Generally, the small craft assume a heading with the wind on one or the other quarter. The keel of the boat will cause the boat to "sail" off the downwind line. Thus the effect of the keel and a quartering wind can cause deflection to the right or left of the wind.

Table 7. The direction of drift of five small craft without drogue compared to the true wind direction and expressed as a percent.

DIRECTION	MARINER	GLASTRON	BARGE	SILVER SKIFF	RUBBER RAFT
DOWNWIND*	02	20	18	15	19
LEFT	53	40	32	40	42
RIGHT	45	40	50	45	38

*Downwind is considered to be any direction that varies less than 5° off the true wind direction.

The angle of deviation from the downwind direction (drift angle) was observed to range from 5° to 45° in the small craft with a greater keel plane area (Mariner, Glastron), and from 5° to 60° in the craft with smaller keel plane area (Silver Skif - Barge), with the exception of the rubber raft (Table 8). At this time we have no explanation for the larger angles observed for the craft with the least keel plane area. There is the possibility that these angles occur because these vessels are more responsive to wind turbulence. As mentioned above, the drift angle can be either to the left or right of the wind. Histograms of the drift angle show that the left angle distribution is almost a mirror image of the right angle distribution. This result indicates that leeway to the left does not behave differently from leeway to the right.

The drift angles observed for a given wind range are listed in Table 8. No mean values of the drift angles are given because the mean values can be misleading because there is such large variability in the size of the angle for a given wind speed. This large variability is probably caused by a complex interaction among the attitude, keel area to sail area ratio, and mass of the small craft, as well as by the wind perturbations.

Table 8. Characteristics of the leeway drift angle for five small craft without drogue.

SMALL CRAFT	WIND SPEED (KNOTS)	RANGE OF ANGLE (DEGREES)	
		LEFT	RIGHT
MARINER	0-5	15-46	9-41
	5-10	7-33	7-44
	10-15	7-40	11-41
	15-20	---	11-40
GLASTRON	0-5	---	17-28
	5-10	9-28	6-46
	10-15	7-36	13-36
	15-20	---	9-45
BARGE	0-5	---	---
	5-10	9-31	14-51
	10-15	6-22	8-38
	15-20	---	16-43
SILVER SKIF	0-5	---	36-53
	5-10	8-50	8-56
	10-15	18-60	8-58
	15-20	20-46	20-48
RUBBER RAFT	0-5	11-25	---
	5-10	---	7-22
	10-15	18-35	9-25
	15-20	20-29	---

--- insufficient data

The effect of attitude can be best shown by observing the size of the drift angle that occured for the same craft at approximately the same wind speed during each of four different experiments. The results for the Silver Skiff are given in Table 9. The drift angle varied by as much as a factor of 7.

Table 9. The drift angle for the Silver Skif at approximately the same wind speed for four different experiments.

WIND SPEED (KNOTS)	DRIFT ANGLE (DEGREES) L=LEFT R=RIGHT
5.1	29R
5.6	8R
5.6	56R
5.1	49R

An attempt was made to determine the effect of mass, keel area/sail area ratio, and wind speed on the drift angle of the five small craft using the data from Tables 2 and 8. An expression for the drift angles incorporating the three variables could not be defined.

Future experimentation is indicated if a full and adequate description of the drift angle predictive function is to occur. However, there is some risk that more experimentation will only provide a rough prediction of the drift angle. The multitude of variables to be considered may preclude exact quantitative predictions of the drift angle.

Small craft equipped with a drogue exhibited much smaller angles than those craft without a drogue. Generally, the range of angles for the four small craft is approximately half that of the craft without drogue.

WAVE EFFECTS

Wave action is expected to have some effect on small craft leeway, but its contribution is, in general, difficult to separate from that of wind speed because of the causal relationship of the two. A detailed analysis of the effect of waves on small craft leeway was not attempted because of the lack of precise sea state data. However, qualitative effects were noted. In experiments 9/2 and 35/2 the wind speed (16 knots) was the same, but the seas were quite different, less than 2 feet high during experiment 9/2 and greater than 4 feet high during experiment 35/2. The leeway values for the small craft in experiment 35/2 were considerably higher than predicted by equation (4) or from the leeway measured in experiment 9/2. From these results one might speculate that an increased sea state will cause an increase in small craft leeway. In the case above, the increase was about 15% above the predicted value.

REFERENCES

Chapline, W. E. (1959) Estimating the drift of distressed small craft, Coast Guard Alumni Association Bulletin 39-42.

James, R. (1966) Ocean Thermal Structure Forecasting, U.S. Naval Oceanographic Office, Washington, D.C.

Mandelbaum, H. (1965) Wind generated ocean currents at Amrum Bank Lightship. Tranactions of the American Geophysical Union, 36, 72.

Mendenhall, W. (1965) Introduction to Statistics, Wadsworth, Belmont California, 305 p.

Meyers, J. J., Holm, C. H. and McAllister, R. F. (1967) Handbook of Ocean and Underwater Engineering, McGraw-Hill, New York.

Smith, C. L. (in press) Determination of the leeway of oil slicks, U.S. Coast Guard Research and Development Technical Report, 45 p.

Tomczak, C. (1964) Investogations with drift cards to determine the influence of the wind on surface currents. Studies on Oceanography, University of okyo Press, Japan.

U.S. Navy Hydrographic Office (1944) Methods for locating survivors adrift at sea on rubber rafts, H.Q. number 235, 25 p.

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APPENDIX

Table 1. EXPERIMENTAL CONDITIONS FOR SMALL CRAFT WITHOUT SEA ANCHOR.

1. MARINER

Experiment/ Exercise	Average Wind Speed (Kts)	Average * Wind Direction	Average Leeway Speed (Kts)	Direction of Small Boat
6/1	5.0	180°	0.63	041°
6/2	15.0	270°	0.82	083°
7/1	3.0	130°	0.37	295°
7/3	5.0	130°	0.39	289°
8/2	7.2	145°	0.36	009°
8/3	4.5	200°	0.35	029°
9/1	11.0	270°	0.59	131°
9/2	16.0	223°	0.88	042°
12/1	5.5	272°	0.39	112°
14/1	12.8	336°	0.73	141°
14/2	14.7	337°	0.73	117°
15/2	7.5	270°	0.33	057°
16/2	10.0	043°	0.61	190°
18/2	8.0	143°	0.36	308°
20/1	10.3	232°	0.65	072°
21/1	5.1	313°	0.22	189°
24/1	11.1	278°	0.73	087°
24/2	9.6	261°	0.51	074°
25/1	3.8	048°	0.30	182°
26/1	11.0	088°	0.55	254°
26/2	12.0	127°	0.50	282°
27/1	4.5	184°	0.21	021°
27/2	6.7	183°	0.41	348°
28/1	12.0	235°	0.73	088°
29/1	15.6	246°	1.07	110°
29/2	16.4	240°	1.23	093°
30/1	11.4	018°	0.73	172°
31/1	8.4	279°	0.39	070°
32/1	5.6	036°	0.36	209°
32/2	5.6	224°	0.16	087°
33/1	10.4	320°	0.64	162°
34/1	14.0	315°	0.83	125°
34/2	13.0	287°	0.92	091°
35/1	16.0	231°	1.13	096°
35/2	16.0	228°	1.39	091°
36/1	9.0	235°	0.64	091°
36/2	9.1	245°	0.58	042°
37/2	9.0	053°	0.77	246°
38/2	11.0	345°	0.93	190°
40/2	15.4	295°	1.11	125°
41/2	16.0	305°	1.04	114°

1. MARINER (CONTINUED)

Experiment/ Exercise	Average Wind Speed (Kts)	Average * Wind Direction	Average Leeway Speed (Kts)	Direction of Small Boat
42/2	11.0	234°	0.69	041°
44/2	12.8	263°	0.83	112°
45/2	11.1	263°	0.82	068°
46/1	13.5	247°	0.73	033°
46/2	10.2	270°	0.92	066°
47/1	7.5	270°	0.53	079°
47/2	11.0	267°	0.80	073°
48/2	11.0	231°	0.75	062°
48/3	11.3	260°	0.89	070°
50/1	2.1	170°	0.37	020°

* Wind direction is from where the wind is blowing.

Direction of small boat is the direction in which boat is moving.

2. GLASTRON

Experiment/ Exercise	Average Wind Speed (Kts)	Average Wind Direction (Degrees)	Average Leeway Speed (Kts)	Direction of boat (Degrees)
16/2	10.0	043	0.47	206
18/2	8.0	143	0.37	313
21/1	5.1	313	0.20	170
24/1	11.1	278	0.79	102
24/2	9.6	261	0.44	053
25/1	3.8	048	0.20	189
26/1	11.0	088	0.55	273
26/2	12.0	127	0.66	294
27/1	4.5	184	0.23	021
27/2	6.7	183	0.44	258
28/1	12.0	235	0.51	074
29/1	15.6	246	0.92	086
29/2	16.4	240	0.95	069
30/1	11.4	018	0.53	171
31/1	8.4	279	0.38	079
32/1	5.6	036	0.33	212
32/2	5.6	224	0.19	085
33/1	10.4	320	0.53	176
34/1	14.0	315	0.75	136
34/2	13.0	287	0.77	105
35/1	16.0	231	0.98	086
35/2	16.0	228	1.15	097
36/1	9.0	235	0.62	074
36/2	9.1	245	0.63	053
37/2	9.0	053	0.67	224
38/2	11.0	345	0.92	184
40/2	15.4	295	1.13	138
41/2	16.0	305	1.10	128
42/2	11.0	234	0.80	047
44/2	12.8	263	0.89	096
45/2	11.1	263	0.83	085
46/1	13.5	247	0.75	044
46/2	10.2	270	0.87	054
47/1	7.5	270	0.53	092
47/2	11.0	267	0.71	085
48/2	11.0	231	0.81	041
48/3	11.3	260	0.79	049
50/1	2.1	170	0.35	018

3. BARGE

Experiment/ Exercise	Average Wind Speed (Kts)	Average Wind Direction (Degrees)	Average Leeway Speed (Kts)	Direction Of boat (Degrees)
10/2	7.4	142	0.37	341
12/1	5.5	272	0.35	108
14/1	12.8	336	0.92	155
14/2	14.7	337	0.58	151
17/1	6.0	157	0.24	357
17/2	5.5	182	0.48	016
18/2	8.0	142	0.39	320
21/1	5.1	313	0.29	187
24/1	11.1	278	0.94	094
24/2	9.6	261	0.62	050
25/1	3.8	048	0.22	191
26/1	11.0	088	0.67	276
26/2	12.0	127	0.76	296
27/1	4.5	184	0.30	038
27/2	6.7	183	0.49	005
28/1	12.0	235	0.65	069
29/1	15.6	246	1.12	093
29/2	16.4	240	1.15	076
30/1	11.4	018	0.61	176
31/1	8.4	279	0.43	084
32/1	5.6	036	0.37	213
32/2	5.6	224	0.25	095
33/1	10.4	320	0.57	178
34/1	14.0	315	0.88	128
34/2	13.0	287	0.82	119
35/1	16.0	231	1.20	081
35/2	16.0	228	1.22	091
36/1	9.0	235	0.77	076
36/2	9.1	245	0.65	050
37/2	9.0	053	0.74	224
38/2	11.0	345	1.09	187
40/2	15.4	295	1.34	140
41/2	16.0	305	1.18	123

4. SILVER SKIF

Experiment/ Exercise	Average Wind Speed (Kts)	Average Wind Direction (Degrees)	Average Leeway Speed (Kts)	Direction of boat (Degrees)
9/1	11.0	270	0.56	105
9/2	16.3	223	0.94	039
14/1	12.8	336	1.17	160
14/2	14.7	337	0.99	169
18/2	8.0	142	0.48	010
21/1	5.1	313	0.30	182
24/1	11.1	278	0.89	068
24/2	9.6	261	0.77	052
25/1	3.8	048	0.21	278
26/1	11.0	088	0.87	232
26/2	12.0	127	1.09	247
27/1	4.5	184	0.47	077
27/2	6.7	183	0.51	047
28/1	12.0	235	0.68	113
29/1	15.6	246	1.39	040
29/2	16.4	240	1.26	108
30/1	11.4	018	1.17	171
31/1	8.4	279	0.48	057
32/1	5.6	036	0.41	224
32/2	5.6	224	0.49	110
33/1	10.4	320	0.71	207
34/1	14.0	315	1.09	098
34/2	13.0	287	1.02	156
35/1	16.0	231	1.17	050
35/2	16.0	228	1.32	068
36/1	9.0	235	0.74	047
36/2	9.1	245	0.62	025
37/2	9.0	053	0.64	183
38/2	11.0	345	1.28	223
40/2	15.4	295	1.12	097
42/2	11.0	234	0.73	062
44/2	12.8	263	0.95	081
45/2	11.1	263	1.19	085
46/1	13.5	247	0.56	042
46/2	10.2	270	1.20	091
47/1	7.5	270	0.74	110
47/2	11.0	267	1.13	065
48/2	11.0	231	0.84	020
48/3	11.3	260	0.77	032
50/1	2.1	150	0.45	006

5. RUBBER RAFT

Experiment/ Exercise	Average Wind Speed (Kts)	Average Wind Direction (Degrees)	Average Leeway Speed (Kts)	Direction of boat (Degrees)
5/2	4.4	173	0.27	328
6/1	15.0	180	1.01	025
6/2	15.0	270	1.03	059
7/1	3.0	130	0.50	308
7/3	5.0	130	0.41	299
10/2	7.4	142	0.44	344
12/1	5.5	272	0.44	110
16/2	10.0	043	0.92	198
17/1	6.0	157	0.32	349
17/2	5.5	182	0.53	009
41/2	16.0	305	1.15	099
42/2	11.0	234	0.73	058
44/2	12.8	263	0.95	092
45/2	11.1	263	1.19	080
46/1	13.5	247	0.56	049
46/2	10.2	270	1.20	055
47/1	7.5	270	0.74	100
47/2	11.0	267	1.13	088
48/2	11.0	231	0.84	022
48/3	11.3	260	0.77	057
50/1	2.1	150	0.45	022

Table 2. EXPERIMENTAL CONDITIONS FOR SMALL CRAFT WITH SEA ANCHOR.

1. MARINER (With Sea Anchor)

Experiment/ Exercise	Average Wind Speed (Kts)	Average Wind Direction (Degrees)	Average Leeway Speed (Kts)	Direction of boat (Degrees)
9/2	16.3	223	0.88	042
16/1	11.1	031	0.40	222
17/1	6.0	157	0.18	356
17/2	5.5	182	0.25	014
18/1	6.6	180	0.33	012
37/1	17.0	030	0.83	172
38/1	11.0	327	0.62	147
40/1	13.0	300	0.74	120
41/1	14.1	330	0.62	129
42/1	11.0	165	0.46	340
43/1	19.1	221	1.01	068
44/1	17.6	244	0.88	101
48/1	10.1	199	0.43	044
49/1	13.5	221	0.76	068
49/2	15.4	221	0.79	084
51/2	9.5	240	0.41	056

2. GLASTRON (With Sea Anchor)

Experiment/ Exercise	Average Wind Speed (Kts)	Average Wind Direction (Degrees)	Average Leeway Speed (Kts)	Direction of boat (Degrees)
16/1	11.1	031	0.30	202
18/1	6.6	180	0.28	348
38/1	11.0	327	0.61	160
40/1	13.0	300	0.67	125
41/1	14.1	330	0.54	141
42/1	11.0	165	0.41	351
44/1	17.6	244	0.74	097
48/1	10.1	199	0.39	053
49/1	13.5	221	0.64	072
49/2	15.4	221	0.80	083
51/2	9.5	240	0.37	065

3. SILVER SKIF (With Sea Anchor)

Experiment/ Exercise	Average Wind Speed (Kts)	Average Wind Direction (Degrees)	Average Leeway Speed (Kts)	Direction of boat (Degrees)
18/1	6.6	180	0.21	330
37/1	17.0	030	0.51	198
38/1	11.0	327	0.37	146
40/1	13.0	300	0.58	127
41/1	14.1	330	0.44	141
42/1	11.0	165	0.43	349
43/1	19.1	221	0.65	073
44/1	17.6	244	0.58	094
48/1	10.1	199	0.19	014
49/2	15.4	221	0.76	096
51/2	9.5	240	0.24	059

4. RUBBER RAFT (With Sea Anchor)

Experiment/ Exercise	Average Wind Speed (Kts)	Average Wind Direction (Degrees)	Average Leeway Speed (Kts)	Direction of boat (Degrees)
15/2	7.5	270	0.19	064
16/1	11.1	031	0.21	196
41/1	14.1	330	0.55	135
42/1	11.0	165	0.20	005
43/1	19.1	221	0.65	082
44/1	17.6	244	0.51	097
48/1	10.1	199	0.18	030
49/1	13.5	221	0.47	079
49/2	15.4	221	0.51	082
51/2	9.5	240	0.26	046

Table 3. Statistical Methods

A. Linear Regression

This method involves fitting a straight line

$$y = a_0 + a_1 x$$

to a set of data points x_i, y_i (where i = 1, 2, --- n) by the least square method. The regression coefficients a_0 and a_1 are computed as follows:

$$a_1 = \frac{\Sigma x_i y_i - \frac{\Sigma x_i y_i}{n}}{\Sigma x_i^2 - \frac{(\Sigma x_i)^2}{n}}$$

$$a_0 = \bar{y} - a_2 \bar{x}$$

where

$$\bar{x} = \frac{\Sigma x_i}{n}$$

$$\bar{y} = \frac{\Sigma y^1}{n}$$

A coefficient of determination, r^2, is computed as follows:

$$r^2 = \frac{\left[\Sigma x_i y_i - \frac{\Sigma x_i y_i}{n}\right]}{\left[\Sigma x_i^2 - \frac{(\Sigma x_i)^2}{n} \quad \Sigma y_i^2 - \frac{(\Sigma y_i)^2}{n}\right]}$$

r^2 can be interpreted as the proportion of total variation about the mean $\bar{y}$ explained by the regression. In other words, r^2 measures the goodness of fit of the regression line. Note that if $r^2 = 1$ we have a perfect fit.

B. F Test

This method uses the ratio of the between variance to the within variance as a basis of deciding whether the sets of data could have arisen by random sampling from the same population.

If the ratio is less than the F statistic (determined from the F distribution table) than one concludes that there is no significant differences among the five small craft. If the ratio is greater than the F statistic then it is concluded that there is significant differences.

The ratio is computed as follows:

$$\text{Between sets} = \frac{n \, \Sigma \, d^2}{k - 1}$$

$$\text{Within sets} = \frac{\Sigma x_s^2}{k \, (n - 1)}$$

where

x_s is the sum of squares of deviation within the sets

d is the deviation of the set mean from the grand mean

k is the number of sets of data

n is the sample size

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